Chapter 9

Commissioning and Operational Issues

Our goal is to collide 70% polarized protons beams in RHIC with luminosity up to 2×10^{32} cm^{-2} sec^{-1}. A_{LL}, A_L, A_{NN}, and A_N are to be measured at STAR and PHENIX, and A_{NN} and A_N at *pp2pp* and possibly other intersections. The statistical errors can be quite small — for example, 10^{-3} in asymmetry for jets with $p_T > 40$ GeV/c is desirable and achievable. Physics measurements will explore a wide energy range: $\sqrt{s} = 50$ to 500 GeV.

In this section we outline an approach to commissioning the polarized proton collider and we discuss several issues for physics running.

9.1 Operational Modes of RHIC for Polarized Proton Running

For normal operation no special operational modes of RHIC are required for the acceleration and storage of polarized protons. Since depolarizing resonances are driven predominantly by vertical orbit excursions, particular care has to be given to the corrected vertical closed orbit and the vertical beam emittance. This means that beam blow-up from beam-beam interactions and stop-bands should be minimized. To avoid depolarization from snake resonances the fractional vertical betatron tune including tune spread has to be kept well within $\frac{1}{6} = 0.1667$ and $\frac{3}{16} = 0.1875$, especially at the energies of the three strongest intrinsic resonances: $G\gamma = 3 \times 81 + (\nu_y - 12)$ [$E = 136$ GeV], $5 \times 81 - (\nu_y - 12)$ [$E = 203$ GeV], and $5 \times 81 + (\nu_y - 12)$ [$E = 221$ GeV]. Also the acceleration rate would have to be at least $\dot{\gamma} = 4.2$ sec^{-1}, which corresponds to $\frac{dB}{dt} = 0.05$ T/sec.

During commissioning, acceleration cycles that allow for polarization measurements at various energies are required, in particular at the injection energy, at energies below and above the 3 strongest intrinsic resonances, and at some intermediate energies: 25 GeV, 50 GeV, and 100 GeV.

9.2 Commissioning

The commissioning approach will be step-wise, beginning with one ring, no polarization, and advancing to both rings polarized at full energy. We expect to commission one ring to 100 GeV in FY2000. Commissioning both rings and to 250 GeV will be done in subsequent years. At the time that RHIC begins polarized proton studies, RHIC will have already been fully commissioned for heavy ions, and the AGS will be a well-understood injector for polarized protons. (E880, the partial snake experiment in the AGS, and E925, the polarimeter calibration at RHIC injection energy, will have been completed.)

It is important for efficient commissioning to optimize the measurement cycle, filling → polarization measurement → filling, and on-line polarization results are required. With an inclusive π^- polarimeter in each ring, we estimate that this cycle can be kept to about 10 minutes, with a 7% polarization measurement from each cycle. We set the spectrometer currents for the polarimeter at the desired kinematic region ($x_F = 0.5$, $p_T = 0.8$ GeV/c). We may also use a CNI polarimeter measuring proton-Carbon elastics. We expect, at the time of commissioning, to use 60 bunches per ring and to have 4×10^{10} protons per bunch. Emittance blow-up from polarization measurement during commissioning is not an important issue because we will measure the polarization at energies away from resonances. Emittance blow-up is largest at injection, and we will use a limit of an increase of $\Delta\varepsilon_N = 10\pi$ mm mrad. From Table 8.2, we use a factor of 10 less beam for commissioning. The measuring time is then 180 seconds to make a 7% polarization measurement. The emittance blow-up is 3π mm mrad. Of the 60 bunches, half would be loaded with spin up and half with spin down, for each cycle. A pipeline readout would store the inclusive π^- tracks seen by the polarimeter, tagged for the spin direction of the bunches. Polarization is obtained nearly on-line as discussed in Chapter 8.

Besides the polarimeters, each ring will have an rf spin-flipper. This device can be used to measure the spin tune. At the resonant frequency of the device, the polarization can be adiabatically reversed. If left on for a longer time, the polarization will be driven to zero. In this way, the resonant frequency can be identified: by measuring the polarization at different frequencies. The spin tune is then the resonant frequency divided by the revolution frequency:

$$\nu_{sp} = \frac{f_{rf,res.}}{f_{rev}}.$$

The spin tune can be measured very accurately, and the tune should be 0.500 if the Siberian Snakes are set up properly.

9.2.1 Commissioning Steps–One Ring Only

A. Snakes off, establish bunched beam at 25 GeV to flat-top energy (100 GeV in FY2000) – perform closed orbit corrections, etc.

B. Turn on one snake, no polarization, 25 GeV

– adjust V, H, trim supplies for Snake to center beam using beam position monitors (BPMs)

– adjust tune to correct for Snake tune shift (use tune-meter)

– adjust multipole correction magnets for sufficient storage time (>10 min.) (use current transformer)

– Snake coupling correction using skew quads

– measure orbit excursion inside Snake (this uses the BPM at the center of the Snake)

C. Turn on second Snake in ring (alone), and repeat B.

– balance orbit excursion in both Snakes

D. Both Snakes on – check excursions and lifetime (don't anticipate a problem)

E. Polarimeter check-out

– target in/out, accidentals (polarimeter has been calibrated in E925 at RHIC injection energy)

F. Transverse polarization in one ring, 25 GeV, both Snakes on (note that the Snakes are not necessary to maintain polarization at 25 GeV)

– commission polarimeter – look for asymmetry

– no asymmetry? Check AGS polarization. If OK, vary transfer line.

– observe asymmetry. Check repeatability; put in $P = 0$, measure $P = 0$; turn off both Snakes, should measure $P = P_{AGS}$; turn off one Snake, should measure $P_y = 0$; small scan of (X, p_T) vs. NA^2 to optimize and check polarimeter.

– measure spin tune with rf spin flipper

– measure spin tune vs. energy – constant, 1/2 if the Snake settings are correct. Otherwise, there are several possible effects. If the spin tune depends on energy, then the Snakes would not be exactly 180° apart in ring field integral. This is not expected (and is not correctable). If the spin tune is independent of energy but not 1/2, two effects can contribute: the Snake axes are not orthogonal, or the Snake precession angles are not 180°. These can be explored and corrected by adjusting each separately.

– commission spin flipper

– at resonant rf frequency, measure polarization vs. time on to establish spin flip

– many spin flips – measure polarization loss from spin flipper

G. Accelerate – steps determined by spin resonances (measure just before/after expected resonance). Larger resonances at about 120, 140, 220, 240 GeV. (FY2000 will be below these resonances.)

– need to check spin tune at lower energies (expect different effective lengths of Snake magnets vs. orbit excursion)

– if the polarization is reduced or lost, measure spin tune and adjust Snakes

– also measure asymmetry in polarimeter at 200 GeV, the energy where the π^- asymmetry was measured at FNAL. This would give an absolute polarization for the beam. (FY2001)

H. Commission the spin rotators (FY2001)

– unpolarized beam: turn on each rotator and adjust so that there is no orbit shift, match the rotators by comparing BPMs in centers

– turn on each rotator, one at a time, and with polarized beam use polarimeters to measure the predicted P_y at the polarimeter position vs. different excitations of each rotator, and vs. energy

– with pairs of rotators energized, measure P_y at the polarimeter location (all polarization should be in the y direction)

– We do not have an approach to measure the longitudinal polarization at the intersection region. We could measure the absence of transverse polarization at the intersection, with the presence of vertical polarization at the polarimeter. Each experiment would need to evaluate the practicality of doing this.

For FY2001 and beyond, the above procedure would be repeated for the second RHIC ring. With two rings, relative luminosity measurements and polarization lifetime measurements would be performed.

9.3 Physics Running–Issues

9.3.1 Bunch pattern

Each bunch is to be injected independently, so the "pattern" of polarization direction for the 60 to 120 bunch positions in each ring can be arranged in an optimal way. At each intersection region the same pairs of bunches interact, but there are different pairs at each intersection. It is typically desirable to collide equal numbers of $(++, +-, -+, --)$ bunches at each experiment, where $+-$ represents a bunch in one beam with polarization up colliding with a bunch in the other beam with polarization down.

One solution which would satisfy all the intersections is to load the bunches of one ring $(+ + - - + + - - + + --$, etc.), and load the bunches of the other ring with $(+ - + - + - + - + - +-$, etc.). The pattern and time of one bunch is given by RHIC to the experimenters. Each experiment chooses collisions to have complete sets of $(++, +-, -+, --)$. This is illustrated in Fig. 9.1.

It may be desirable to correct for polarized proton beam-gas scattering. This can be done with the empty bunches in the abort gaps of each ring, giving intersection combinations of $(0+, 0-, +0, -0)$.

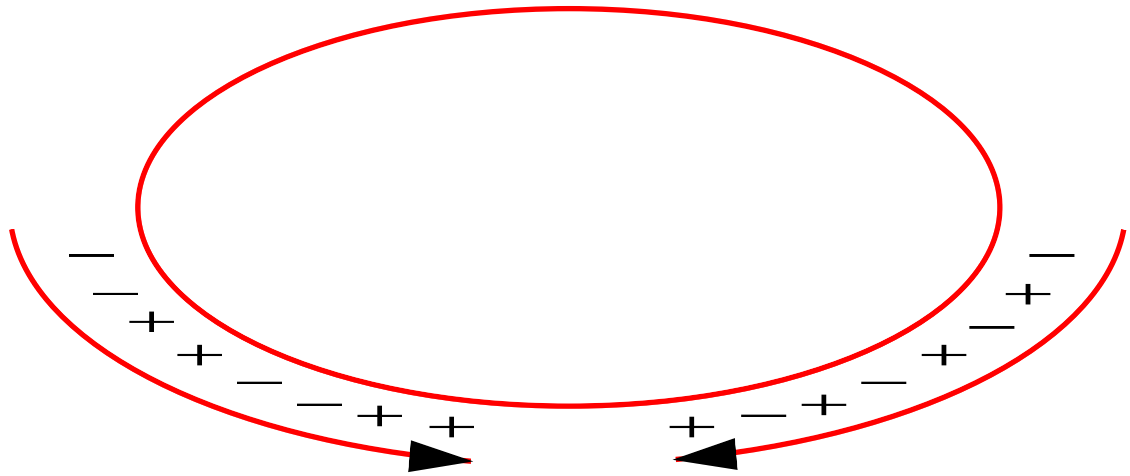

Figure 9.1: The pattern of the polarization signs of the bunches in the two counter-rotating beams in RHIC.

9.3.2 Frequency of Spin Flip

Because the same bunches collide for a given experiment, periodically reversing the spin will reduce systematic errors for asymmetry measurements even further. Polarization reversal will take about one second. The frequency of reversal depends on the effect on luminosity from emittance blow-up, and on polarization loss from the flipping process. Neither is expected to be large.

9.3.3 Recogging

Another tool available to reduce systematic errors is to recog the collisions. This can be done in one second, so that each experiment would then see different pairs of bunches collide. This could be used to randomize the order of the preparation of the bunches, as seen by the experiments. Recogging could also be used to move empty bunches so that each experiment can collect background data for part of the fill. In principle, recogging and spin-flipping can be used to give equal luminosity for $(++, +-, -+, --)$ combinations at an intersection region, although many steps are involved, as well as the assumptions that the number of protons in each bunch and the bunch polarization is unchanged by each step.

9.3.4 Systematic Errors

For each fill, the spin condition changes at each experiment every 100 nanoseconds or 3.6×10^{10} times per hour. In addition, the spin can be reversed for each crossing, possibly once per hour. The collisions can be recogged. And, finally, the pattern can be changed for each fill.

Experiments making particularly sensitive asymmetry measurements may desire to measure relative luminosity of individual bunch crossings. An asymmetry measurement to 10^{-3} requires that the overall relative luminosity be known (or that the bunch luminosities be equal) to 10^{-4}. If the individual bunch crossing luminosities are independent of spin state *or* the spin flip process is independent of spin state, then the luminosities will be equal. If this is not assumed, the experiment can measure the bunch crossing relative luminosity with a factor of 100 more counts in a luminosity monitor than signal. If the signal counts are 10^6, collected over 10^6 seconds, the luminosity monitor must have a rate greater than 100 Hz.

9.3.5 Beam Polarization Measurements

The polarization measurements are unobtrusive at 250 GeV, with $< 0.1\%$ emittance growth to obtain a 7% polarization measurement. At 25 GeV, the emittance growth is 1-2% per measurement for full intensity beams (120 bunches and 2×10^{11} protons per bunch). The frequency of measurement depends on the stability of the system. We assume that a measurement would be made every hour, and the data for the previous hour would be thrown out if the polarization were lost.